Geomorphic modeling of macro-tidal embayment with extensive tidal flats: Skagit Bay, Washington

Lyle Hibler
Battelle-Pacific Northwest Division
Marine Sciences Laboratory
Sequim, WA 98382
phone: (360) 681-3616 fax: (360) 681-4559 email: lyle.hibler@pnnl.gov

Adam Maxwell
Battelle-Pacific Northwest Division
Marine Sciences Laboratory
Sequim, WA 98382
phone: (360) 681-4591 fax: (360) 681-4559 email: adam.maxwell@pnnl.gov

Award Number: N00014-081-0952 & N00014-10-1-0678
http://www.onr.navy.mil/sci_tech/32/reports/annual/

LONG-TERM GOALS

The long-term goal for the project is to better understand processes affecting morphologic changes of muddy tidal flats and to quantify the effects of tidal action, river discharge, and shoreline development (e.g. dikes and jetties) on these changes.

OBJECTIVES

Our objective in this effort is to demonstrate the use of a community numerical model for prediction and investigation of tidal flat morphology and forcing parameters. The Delft3D[1] community model is being evaluated as a physics-based numerical simulation tool for several investigations, and this effort applies it specifically to tidal flat and channel systems.

Within this objective, we examine the relative roles of tidal action, river discharge, and shoreline modification on flow over the tidal flats and resulting effects on morphologic modeling. From a model-tuning perspective, this objective includes advancing the understanding of the sensitivity of the model to parameter value adjustments and to the inclusion or exclusion of specific sediment transport processes and characterization in tidal flat and channel systems.

The model fidelity should be improved by incorporation of observational data for configuration, assignment of boundary and initial conditions, and sediment source-term characterization, and for calibration and validation efforts.

[1] http://www.deltares.nl

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2012**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Geomorphic modeling of macro-tidal embayment with extensive tidal flats: SkagitBay, Washington**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Battelle-Pacific Northwest Division Marine Sciences Laboratory Sequim, WA 98382**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**9**	

APPROACH

An open-source modeling software, Delft3D-FLOW, was used to estimate circulation, heat, salt, sand, and mud transport. Corresponding geomorphology changes also were estimated using the integrated Delft3D-MOR submodel. Measured river discharge, predicted tides, bathymetry, wind, and density-driven flow were incorporated into the model. Several simulations were conducted over the course of the last year. These simulations were designed to evaluate the sensitivity of the geomorphologic model of Skagit Bay to river typical discharges to Skagit Bay, tidal forcing, episodic discharge events, and shoreline features. The circulation model has been evaluated in previous years, along with the response to shoreline changes. The focus has been on the evaluation of the Delft3D-FLOW sediment transport and geomorphology models in response to varying river flow conditions and sediment morphology initial conditions.

Both Mr. Lyle Hibler and Dr. Adam Maxwell conducted model simulations. Lyle Hibler focused on project management, model experimental design, reporting, and interaction with other program participants. Adam Maxwell focused on carrying out numerical experiments, sediment transport and morphology, and data visualization and management.

WORK COMPLETED

The division of Skagit River flows between the north and south forks was computed by a two-dimensional vertically averaged submodel (Figure 1). The total flow as measured by the U.S. Geological Survey (USGS) at the Mt. Vernon gage (station 12200500) is shown in Figure 2. In previous work, we considered three separate models with low, medium, and high runoff (fall 2008, summer 2009, and winter 2009, respectively). In the present model, we have extended the model to run continuously from 1 January–1 August 2009, in order to examine the effects of model spin-up time on morphology and ensure that the Tidal Flats field campaign time period was simulated. The low-flow period is now in early-mid spring, with comparable flows to those of fall 2008. January 2009 includes flows from runoff events that peak at about 2300 m^3/s (a 10-year flood event was estimated at Mt. Vernon to have a peak flow of about 3228 m^3/s).[2] Water temperature of the Skagit River was developed by computing an average for each day of the simulation, based on 1974-1993 water quality data from USGS Station 1220500.

Both mud and sand loads were applied to the north and south forks of the Skagit River according to relationships developed by the USGS (Curran et al., 2011). A single mud class and two sand classes were specified in the model, with 0.25-mm sand introduced in Skagit River, and an initial bed of 1-mm-diameter sand was specified for the tidal flat region. This grain size is consistent with field data provided by K. L. Webster (University of Washington) for the tidal flat. The bay bathymetry was permitted to adjust according to the redistribution of bed sand and riverine sand and mud, while the river bed was maintained as a rigid boundary. Simulations in the previous year's work were performed using an initial bed of 1-mm sand specified over the entire bay domain (white grid of Figure 1), but this led to unreasonable scour and deposition patterns in flow constrictions. In order to mitigate this, only the green-shaded area in Figure 1 was supplied with sediment initially.

Water temperature and salinity at the tidal boundary were adapted from (Moore et al., 2008). Wind forcing was applied to the circulation model; these data were made available by Washington State

[2] Source: http://www.skagitriverhistory.com/PDFs/Chapter8.pdf

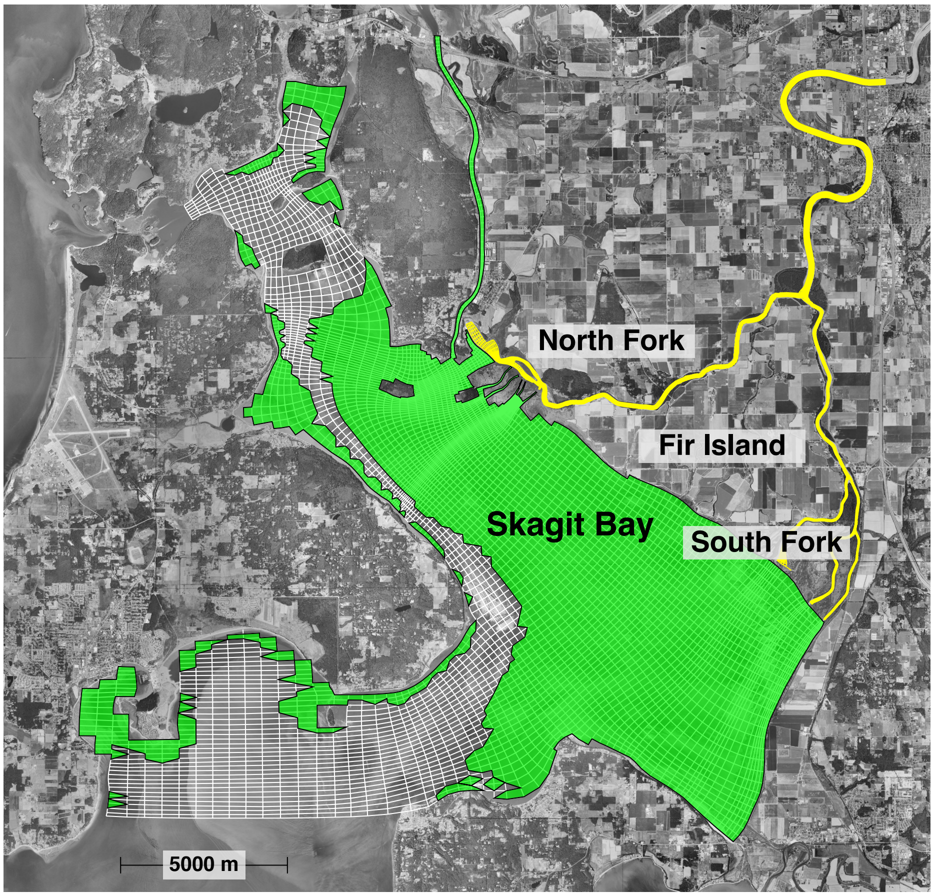

Figure 1: Delft3D model grid. White grid as shown for the bay region is a 10-layer 3-dimensional model, and the yellow grid shown for the river is the depth-averaged submodel. Green shaded region shows region of initial bed sediment supply.

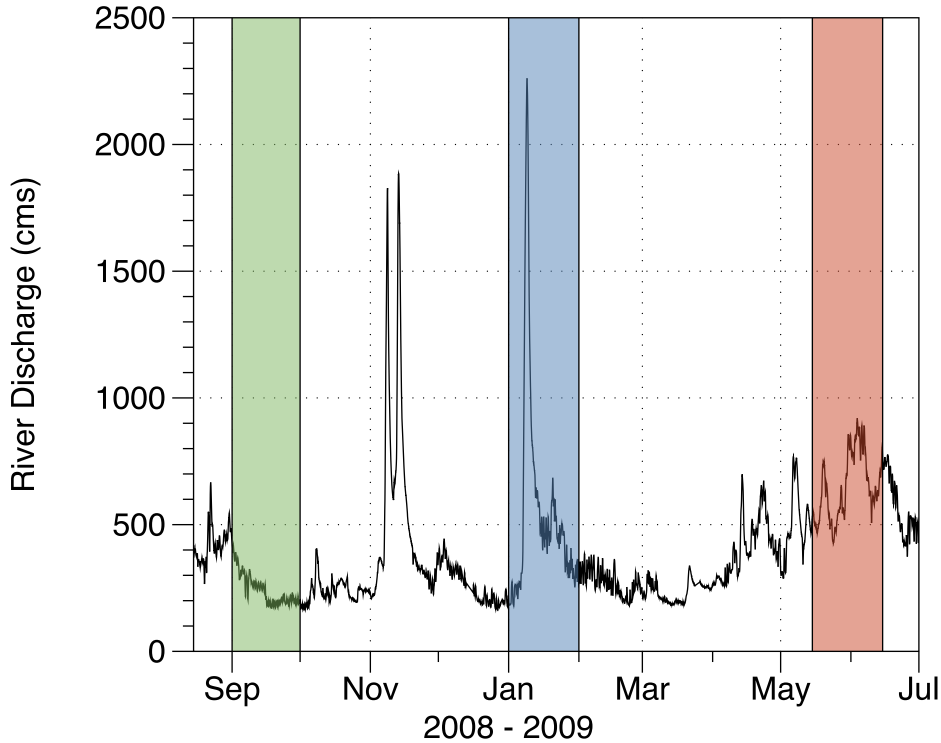

Figure 2: Skagit River discharge measured at Mount Vernon, as specified for the upstream boundary condition of the depth-averaged submodel.

University.[3] Predicted tides were applied along the southern boundary of the model (extending southeast from Crescent Harbor on Whidbey Island to the west shore of Camano Island) and along a short boundary to the west of Deception Pass on the northwest corner of Whidbey Island using Xtide (Flater, 2010). In the previous year's study, we noted that the spring tide range varied from 2.4 m at Deception Pass to 3.5 m at Crescent Harbor.

Because observations have indicated that wind-generated waves may be significant, we also ran a preliminary test with the Delft-SWAN model. We used a steady swell boundary of 0.5 m and 4 s, using measurements from a buoy in the neighboring Strait of Juan de Fuca as an upper limit and winds as noted previously. The work of Raubenheimer et al. (2012) indicates that this approach is not adequate to describe the wave field, but our primary interest was in determinining whether the increased shear stress due to wave forcing would produce a significant change in the morphology model.

RESULTS

Considering total erosion over the flats over the 7-month period of the simulation, we found that the initial bed sediment was entirely depleted along the edge of the main channel, indicating that our "bedrock" area should likely extend further into the shallow regions. However, this bedrock delineation was largely effective at reducing the aforementioned scour regions in the main channel and northern part of the bay. An additional experiment indicated that increasing sand size in the bay to 2 mm would

[3]http://weather.wsu.edu (Fir Island Station). Data provided courtesy of Washington State University AgWeatherNet. Data are copyrighted by Washington State University and used in our study with permission.

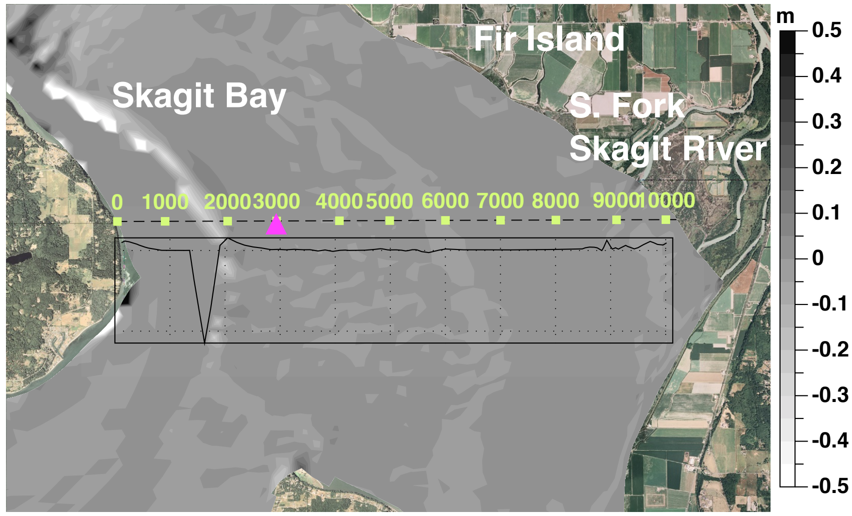

Figure 3: Predicted erosion and deposition pattern at the end of July, with wind-generated waves. Inset graphic shows the bed change along the transect.

substantially decrease erosion rates as well, but we do not have sufficiently high-resolution mapping of the bay sediment to initialize the model with spatially varying sediment sizes at this time. Mud fractions in the model are transported relatively easily, even from the tidal flats, and eventually exported from the model (primarily through Deception Pass; cf. Feely and Lamb (1979)).

Figure 3 shows the predicted final erosion pattern for the bay at the end of July, with wind waves applied, and the inset graphic shows a slice along the 10-km transect. Note the large amount of erosion at the edge of the main channel, which was due to transport of the initial bed sediment away from the edge of the bedrock channel. Some spatial patterns are evident in the erosion, possibly indicating how channels would develop over time in the bed. It would be interesting to simulate a longer time period, although computational power is currently an issue with the model domain.

Considering the actual rate of erosion on a monthly basis, we see that erosion/deposition rates on the flats were on the order of ±1 cm, with larger amounts of deposition near the mouth of the river (Figure 4). This sediment was not significantly reworked over the course of the simulation and essentially remained where it was dumped by the river during the January 2009 storm. One purpose of adding wind-generated waves to the model was to find out if they would enhance shear stress enough to move that pile of sediment offshore, or at least flatten it locally. As shown in Figure 5, this was the case. Whereas bed elevation changes in the middle of the transect appear to be slightly lower on a monthly basis, due to broadening of the affected area, they were significantly more variable month-to-month near the mouth of the river due to wave action. More accurate wave boundary conditions should be developed, but this preliminary test indicates that wind-generated waves are necessary in order to redistribute river sediment (sand) along the shore. It is not clear at this time how realistic the behavior of the model is with respect to sand morphology, as we found that initial conditions of the sediment bed and its size characteristics are significant in this case. This also illustrates the importance of such sensitivity analyses, particularly when performing simulations in data-limited areas.

In examining the significance of river inputs, it is also instructive to look at a point measurement. In this case, we consider the total suspended sediment (TSS; sand and mud fractions) at the 3000-m station on

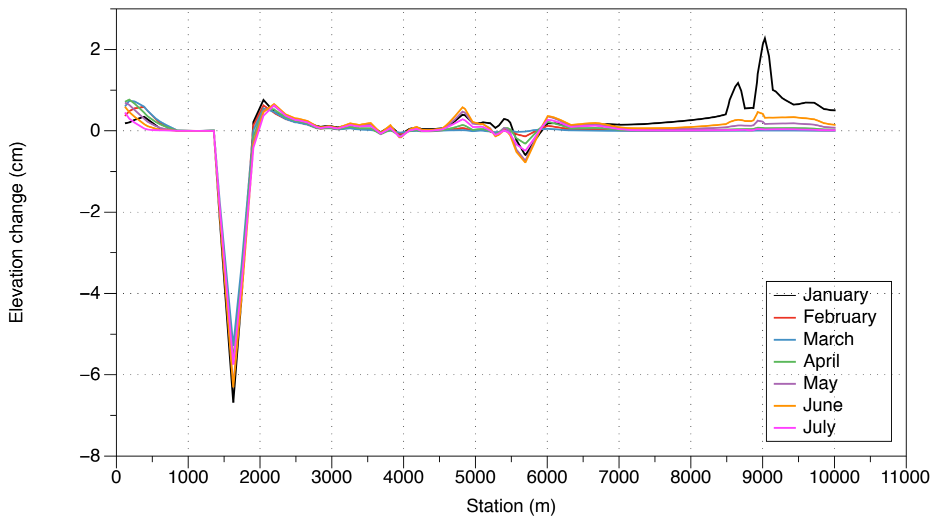

Figure 4: Erosion on a monthly basis across the transect shown in Figure 3. Lines are colored by month, with the most notable change being in January during the high-flow event.

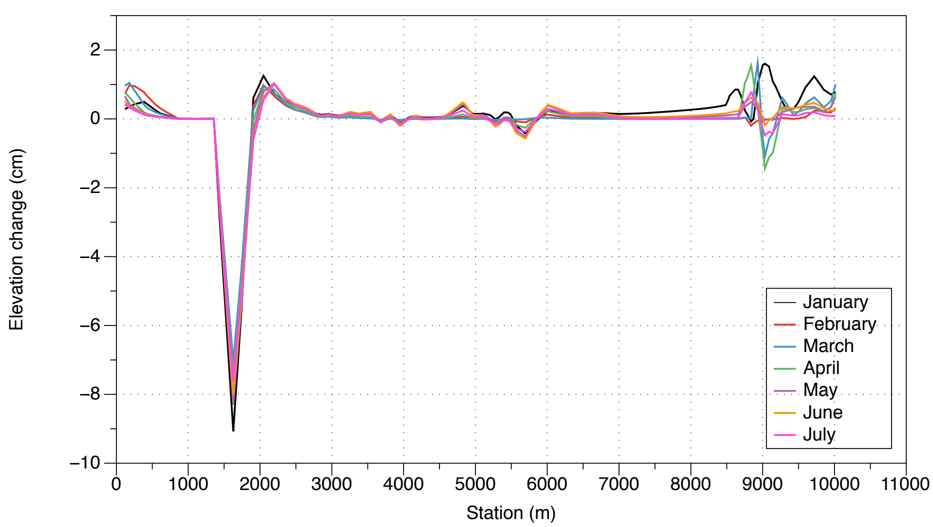

Figure 5: Erosion on a monthly basis across the transect shown in Figure 3. Wind-generated waves were simulated in this case. Lines are colored by month, with the most notable change being in January during the high-flow event.

the transect shown in Figure 3, and at −2-m elevation (relative to NAVD88 datum). Water-surface elevation and TSS are shown as a function of time in Figures 6 and 7, with river discharge on the same axes for convenient comparison. Due to the direct relationship between river discharge and sediment supply, we can easily see that TSS increased during the storm event in January, and typically trended higher with increased supply from the river. The lower-frequency episodic bursts of increased TSS appear to coincide with spring tides, and this dependency was also noted by Webster et al. (2011). However, the simulated TSS appears to be generally lower than was measured in June 2009, even with enhanced shear stress due to waves. Figure 7 shows that TSS is higher on average when waves are

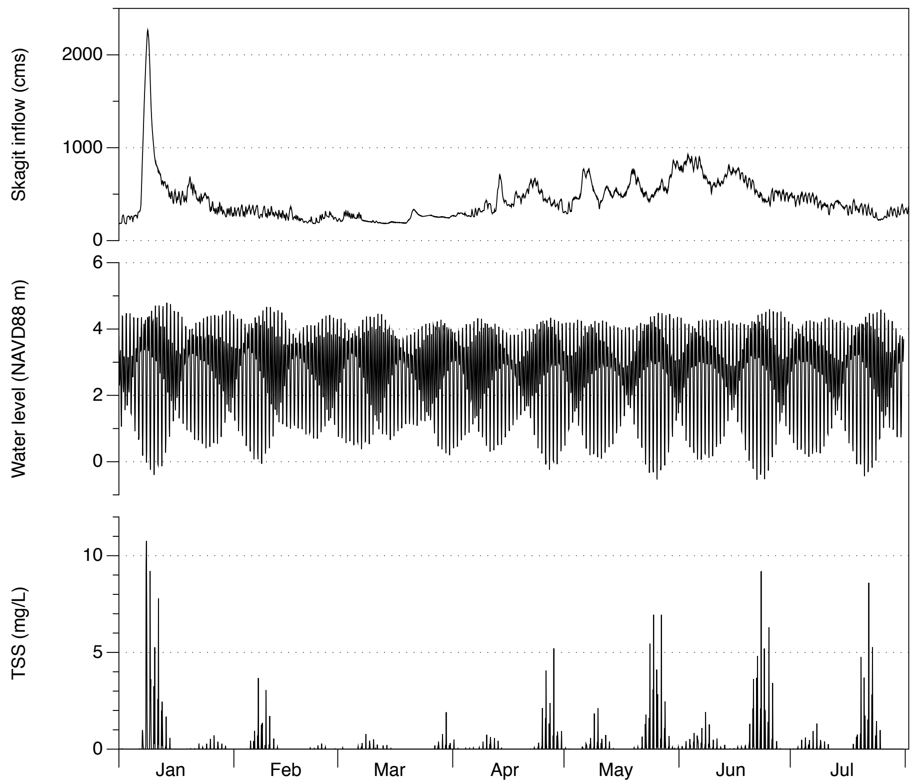

Figure 6: Total suspended sediment (TSS), water surface elevation, and river discharge for the period of simulation. Point records were extracted at the 3000-m station on the transect shown in Figure 3, and TSS was taken at the -2-m elevation.

included in the simulation, and waves appear to extend the effects of the spring tidal cycle by increasing the duration of high TSS events. Additional analysis is required to confirm this hypothesis.

IMPACT/APPLICATIONS

The impact from this work will be further evaluation of the ONR/Delft community model for geomorphological simulation in an environment that is of interest to the Office of Naval Research and in the DoD-Navy, where the software is already being used for other applications. Sensitivity analyses produced in this study will be useful in assessing the data requirements for simulation in data-limited areas. The focus over the last year has been in gaining understanding of the impacts of tidal, seasonal and episodic forcing, and shoreline development on geomorphology with implications to tidal flat morphology.

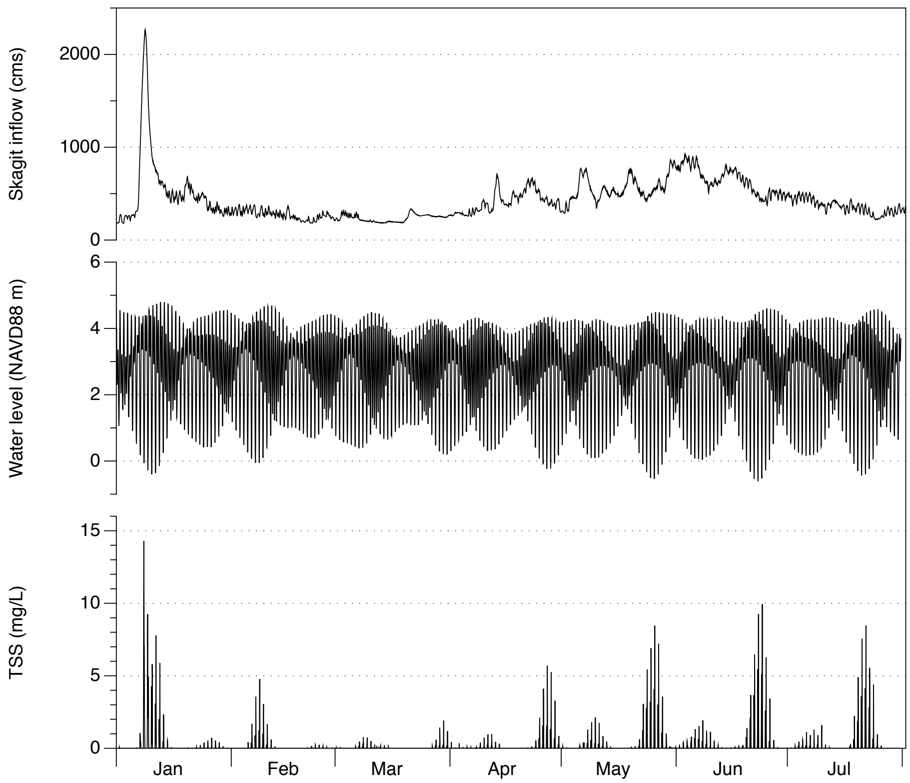

Figure 7: Total suspended sediment (TSS), water surface elevation, and river discharge for the period of simulation. Point records were extracted at the 3000-*m *station on the transect shown in Figure 3, and TSS was taken at the -2-*m *elevation. Wind waves were present in this case.

TRANSITIONS

None at this time.

RELATED PROJECTS

Battelle has recently received a ONR subaward (N000141010678) to evaluate the exchange of water over reefs, into lagoons, and through reef passes in the Republic of Palau.

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PUBLICATIONS

No publications.